

Applied nutritional investigation

Comparison of fat-free mass and body fat in Swiss and American adults

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Abstract

Objective: No current studies have compared North American with European body composition parameters, i.e., fat-free mass (FFM), body fat (BF), and percentage of BF (%BF) in large populations. This study compared FFM, BF, and %BF values derived from two bioelectrical impedance analysis (BIA) equations (Geneva and National Health and Nutrition Examination Survey [NHANES]) in Swiss subjects and compared FFM, BF, and %BF values of white Swiss with those of white North American adults with the same BIA equations.

Methods: Healthy adults (3714 men and 3199 women), ages 20 to 79 y, in Switzerland were measured by single-frequency BIA and compared with means and standard deviations for body mass index and body composition parameters obtained from the NHANES III study (United States; n = 2538 men, 2862 women). FFM was calculated with the Geneva and NHANES equations.

Results: Mean FFM_{GENEVA} values did not differ from FFM_{NHANES} values in men but was significantly lower (−1.5 kg) in women. FFM and BF values in American men, who weighed 4.2 to 12.0 kg more than the Swiss men, were significantly higher (+2.1 to +6.0 kg and +1.5 to +6.4 kg, respectively) than those in the Swiss men. FFM and BF values in American women, who weighed 2.3 to 12.1 kg more than the Swiss women, were significantly higher (+1.3 to +2.1 kg and +4.8 to +11.8 kg, respectively, except FFM in subjects ages 20 to 29 y and BF in those ages 70 to 79 y) than FFM_{GENEVA} values in Swiss women. FFM in American women was significantly lower (+1.3 and +1.9 kg) and non-significantly higher than FFM_{NHANES} in Swiss women.

Conclusion: NHANES and Geneva BIA equations estimate body composition equally well in men, but further research is necessary to determine the discrepancies in FFM between BIA equations in women. The greater weight of the American subjects yielded higher values for FFM, BF, and %BF in American than in Swiss men and women. © 2005 Elsevier Inc. All rights reserved.

Keywords:

Bioelectrical impedance analysis; Fat-free mass; Body fat; Bioelectrical impedance analytically measured fat-free mass; Body composition

Introduction

Significant changes in body composition occur over a lifetime. Progressive increases in body fat (BF) and de-

creases in fat-free mass (FFM) during adulthood have been noted [1]. Excess adiposity, increased body fatness (percentage of BF [%BF]), and depletion of FFM or muscle mass are associated with certain chronic diseases, such as cardiovascular disease [2] and respiratory insufficiency [3], respectively. Significant overall weight gains have been reported in recent years in North American and European populations [4]. National surveys including large samples of healthy people are needed to generate reference data for

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body composition parameters that describe differences expected by sex and age during adulthood, with specific reference to fat and muscle mass, to develop ranges of normal values and thus promote health.

Weight and body mass index (BMI) alone are inadequate to detect underlying changes in FFM and fat mass with age and disease [5]. Use of direct body fatness measures and decreased reliance on BMI will lead to a better understanding of the U- or J-shape distribution of obesity and mortality rate [6], the relation between obesity and mortality rate [6], and the relations among obesity, aging, sarcopenia, and morbidity and mortality rates for chronic diseases.

Currently there are no large studies available that have compared North American with European body composition parameters. Further, there is little information on FFM, BF, and %BF in large populations [7,8]. Recent advances in body composition technology, such as bioelectrical impedance analysis (BIA) and dual-energy x-ray absorptiometry (DXA), permit the determination of FFM and BF in large populations and comparisons between different populations [9]. Reference data for FFM and BF can also serve as baseline data for evaluation of longitudinal body composition changes in the population.

BIA equations to estimate FFM in North American populations recently have been validated [10] and then used to determine mean values of FFM, BF, and %BF by age and sex in non-Hispanic white, non-Hispanic black, and Mexican-American participants of the Third National Health and Nutrition Examination Survey (NHANES III) [9]. Kyle et al. [11] developed and validated a BIA equation to predict FFM in Swiss subjects and recently reported percentiles of FFM, BF, and %BF in healthy Swiss adults [1].

The purpose of this study was to determine 1) the validity of the NHANES III versus the Geneva prediction model and compare estimated values of FFM, BF, and %BF in a large sample of healthy Swiss adults and 2) the temporal changes in body composition calculated by the two equations (Geneva and NHANES) of Swiss white versus North American non-Hispanic white adults.

Materials and methods

Swiss subjects

Healthy adults (3714 men and 3199 women), ages 20 to 79 y, were non-randomly recruited by offering free BIA measurements at trade fairs, leisure clubs, and fun runs and among public administration staff and their relatives who participated in Switzerland and are identified as “Swiss” [1]. All subjects were ambulatory Western Europeans (whites) who had no known pathologies or physical handicap. Subjects were excluded if they had a doctor visit for “illness” or were hospitalized within 6 mo of the BIA measurement. Subjects with water or electrolyte imbalances (e.g., edema, ascites), skin abnormalities (e.g., pachydermia secondary to

hypothyroidism), and an abnormal body geometry (e.g., amputation, limb atrophy) that might interfere with BIA measurements were excluded.

The protocol to perform BIA measurements and obtain physical activity, health status, and medication information on Geneva subjects was approved by the Geneva University Hospital ethics committee, and subjects gave written informed consent.

NHANES data

The NHANES data included a nationally representative sample of non-Hispanic white, non-Hispanic black, and Mexican American subjects. Anthropometric, BIA, and body composition results of a subset of 2538 non-Hispanic white men and 2862 non-Hispanic white women ages 20 to 79 y, as reported by Chumlea et al. [9], were used in the present study. Means and standard deviations data for height, weight, BMI, BIA-derived resistance and reactance, and body composition parameters from the recent NHANES III study by Chumlea et al. [9] were compared with Swiss results. The NHANES III data are identified as “US.” Bioelectrical resistance was measured in the NHANES participants by the Valhalla 1990B Bio-Resistance Body Composition Analyzer (Valhalla Scientific, San Diego, CA, USA) and then converted to RJL-equivalent resistance values by using the linear model described by Chumlea et al. [9]. FFM was estimated with the NHANES III BIA equation.

Anthropometric measurements and BIA in Swiss subjects

Body height was measured to the nearest 0.5 cm and body weight to the nearest 0.1 kg on a balance beam scale. Subjects wore indoor clothing and no shoes.

FFM and BF were assessed by BIA as previously described [12]. Whole-body resistance was measured with four surface electrodes placed on the right wrist and ankle. Briefly, an electrical current of 50 kHz and 0.8 mA was produced by a generator (Bio-Z², Spengler, Paris, France; or RJL-101, RJL Systems, Clinton Township, MI, USA) and applied to the skin by using adhesive electrodes (3M Red Dot T, 3M Health Care, Borken, Germany) with the subject lying supine [13]. The skin was cleaned with 70% alcohol before application of the contact electrodes. Because the Geneva equation was developed with a Xitron BIA Analyzer (Xitron Technologies, San Diego, CA, USA), the Bio-Z², and the RJL-101, instruments were cross-validated at 50 kHz against the Xitron 4000B Analyzer. No significant differences were found for resistance at 50 kHz between the Xitron 4000B, the Bio-Z², and the RJL-101 devices. Earthman et al. [14] previously reported no significant differences in repeated resistance determinations at 50 kHz in the same adults between the Xitron 4000B and the RJL-101 devices.

FFM prediction equations

FFM was determined with the Geneva [11] and NHANES III [10] equations.

$\text{FFM}_{\text{GENEVA}} (\text{kg}) = -4.104 + (0.518 \times \text{height}^2 [\text{cm}]/\text{resistance} [\Omega]) + (0.231 \times \text{weight} [\text{kg}]) + (0.130 \times \text{resistance} [\Omega]) + (4.229 \times \text{sex} [1 \text{ for men and } 0 \text{ for women}])$

This equation was previously validated against DXA (Hologic QDR-4500, whole-body version 8.26a:3) [11] in adults and further validated in healthy elderly subjects ($n = 205$) [15].

Men: $\text{FFM}_{\text{NHANES}} (\text{kg}) = 10.678 + 0.262 \times \text{weight} (\text{kg}) + 0.652 \times \text{height}^2 (\text{cm})/\text{resistance} (\Omega) + 0.015 \times \text{resistance} (\Omega)$

Women: $\text{FFM}_{\text{NHANES}} (\text{kg}) = 9.529 + 0.168 \times \text{weight} (\text{kg}) + 0.696 \times \text{height}^2 (\text{cm})/\text{resistance} (\Omega) + 0.016 \times \text{resistance} (\Omega)$

BF (kg) = body weight (kg) – FFM (kg) for Swiss and US subjects

Statistics

StatView 5 (Abacus Concepts, Berkeley, CA, USA) was used for statistical analysis. The age groups were defined at 10-y intervals (20 to 29, 30 to 39, etc.). Results are expressed as mean \pm standard deviation. Paired t tests were used to identify differences in FFM, BF, and %BF between Geneva and NHANES equations by sex and age groups in Swiss subjects. Two-factor analysis of variance (ANOVA) was used to evaluate the interaction between FFM, BF, and %BF and age. Statistical significance was set at $P < 0.05$ for all tests. Significant differences between two means were calculated between the Swiss population by Geneva and NHANES prediction equations and the US population (NHANES equation) data as follows [16, pages 128 and 129]: 1) the difference between groups is represented as $x_1 - x_2$; 2) the standard error of the difference is represented as $\sqrt{(s^2_1/n_1 + s^2_2/n_2)}$, where x is the group mean and s is the standard deviation. The 95% confidence limits for the difference are represented as mean difference $- 1.96 \times$ standard error and mean difference $+ 1.96 \times$ standard error. Results were considered significant if they did not reach 1.

Results

Table 1 presents the anthropometric characteristics of the Swiss and US men and women. The US subjects were significantly taller for men ages 40 to 69 y and women ages 60 to 69 y, and US women ages 20 to 29 y were significantly shorter than Swiss subjects. Mean values for weight (Table 1, Fig. 1) and BMI were significantly higher for US subjects ($\text{BMI} = +2.0$ to 2.9 kg/m^2 for men and $+2.2$ to 4.5 kg/m^2 for women) than for Swiss subjects. Mean resistance (Table 1) was greater in 30- to 59-y-old Swiss men and in 30- to

Table 1
Anthropometric and bioelectrical impedance characteristics of healthy non-Hispanic white Swiss and US subjects

Age (y)	Height (cm)		n	Weight (kg)		Body mass index (kg/m ²)		Resistance (Ω)		Height ² /resistance (cm ² /Ω)		
	n	Swiss		US	Swiss	US	Swiss	US	Swiss	US		
Men												
20–29	718	178.2 ± 6.9	384	177.5 ± 6.7	73.4 ± 9.1	79.2 ± 16.6*	23.1 ± 2.3	25.1 ± 4.9*	477 ± 49	473 ± 59	67.4 ± 8.6	67.7 ± 9.9
30–39	1059	177.1 ± 6.9	436	177.8 ± 6.8	75.0 ± 9.4	84.0 ± 17.1*	23.9 ± 2.5	26.5 ± 4.6*	472 ± 48	464 ± 60*	67.2 ± 8.7	69.5 ± 11.3*
40–49	972	175.6 ± 6.8	410	177.3 ± 6.7*	75.5 ± 9.6	86.0 ± 17.0*	24.5 ± 2.6	27.3 ± 4.9*	468 ± 47	456 ± 62*	66.7 ± 8.5	70.4 ± 11.5*
50–59	552	173.4 ± 6.5	396	176.7 ± 6.2*	74.9 ± 9.9	86.9 ± 15.0*	24.9 ± 2.9	27.8 ± 4.6*	464 ± 45	454 ± 61*	65.4 ± 7.8	70.1 ± 9.9*
60–69	265	171.3 ± 6.8	465	175.3 ± 6.3*	74.4 ± 10.0	84.9 ± 14.7*	25.3 ± 3.0	27.6 ± 4.2*	469 ± 45	467 ± 63	63.2 ± 7.6	67.0 ± 9.9*
70–79	148	171.7 ± 6.8	447	172.4 ± 6.7	75.1 ± 10.4	79.3 ± 13.3*	25.5 ± 3.3	26.7 ± 4.0*	476 ± 50	471 ± 63	62.7 ± 8.1	64.3 ± 9.9*
Women												
20–29	697	165.9 ± 6.4	426	163.6 ± 6.7*	58.9 ± 7.4	63.2 ± 14.3*	21.4 ± 2.3	23.6 ± 5.1*	590 ± 61	588 ± 77	47.2 ± 6.1	46.4 ± 7.1
30–39	798	164.7 ± 6.2	543	164.6 ± 6.3	59.0 ± 8.3	69.1 ± 18.0*	21.7 ± 2.7	25.5 ± 6.5*	577 ± 59	567 ± 74*	47.6 ± 6.3	48.7 ± 7.7*
40–49	780	163.0 ± 5.9	454	163.4 ± 6.1	59.7 ± 8.7	70.7 ± 16.8*	22.4 ± 2.9	26.6 ± 6.5*	561 ± 56	569 ± 84*	47.9 ± 6.0	48.0 ± 7.9
50–59	489	162.3 ± 5.9	454	162.4 ± 6.0	61.8 ± 9.2	73.9 ± 17.4*	23.5 ± 3.2	28.0 ± 6.4*	559 ± 59	559 ± 81	47.8 ± 6.4	48.2 ± 7.6
60–69	237	159.4 ± 6.1	447	160.8 ± 6.1*	63.1 ± 10.4	70.3 ± 15.1*	24.8 ± 3.8	27.2 ± 5.6*	558 ± 62	573 ± 84*	46.2 ± 6.4	46.2 ± 7.6
70–79	198	158.2 ± 6.1	538	158.3 ± 6.8	64.8 ± 10.9	67.1 ± 14.5*	25.9 ± 4.2	26.7 ± 5.3*	560 ± 64	568 ± 82*	45.3 ± 6.3	45.2 ± 8.0

NHANES, National Health and Nutrition Examination Survey; US, American

* Difference between population means (see MATERIALS AND METHODS); Geneva and NHANES data significant.

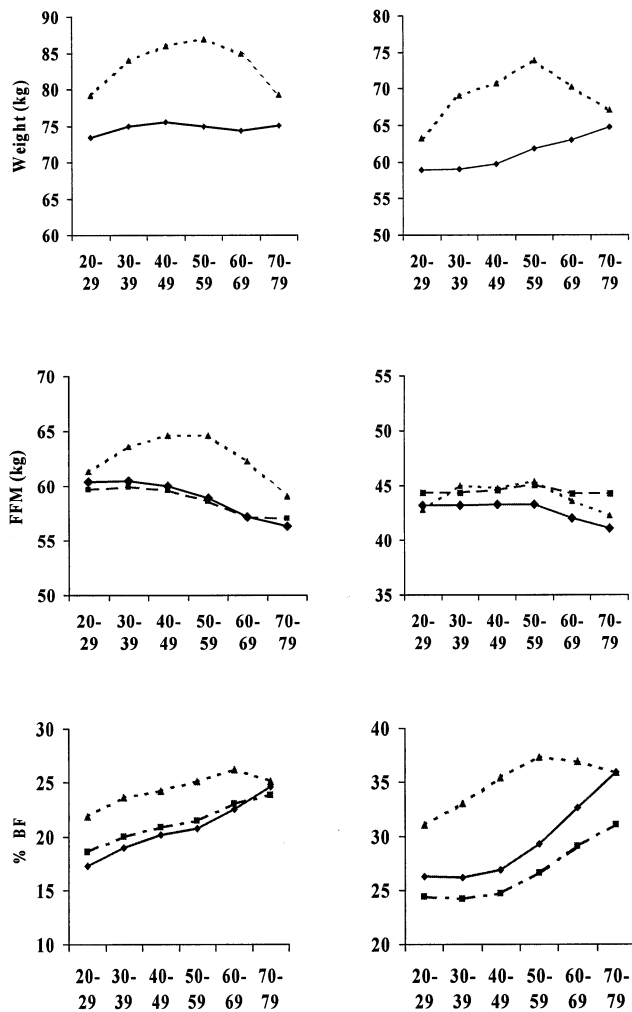


Fig. 1. Mean values for weight (kg), FFM (kg), and %BF in non-Hispanic white men (right) and women (left) by 10-y age groups from 20 to 80 y for American men and women (triangles), Geneva men and women by the Geneva equation (diamonds), and Geneva men and women by the National Health and Nutrition Examination Survey equation (squares). %BF, percentage of body fat; FFM, fat-free mass.

49-y-old and 60- to 69-y-old Swiss women than in US men and women, respectively. Men had smaller resistance and larger $\text{height}^2/\text{resistance}$ than did women, which is consistent with greater fluid volume and larger FFM in men. $\text{Height}^2/\text{resistance}$ was significantly higher in US men ages 30 to 79 y and US women ages 30 to 39 y than in Swiss men and women, respectively.

Fat-free mass

Paired *t* tests between $\text{FFM}_{\text{GENEVA}}$ and $\text{FFM}_{\text{NHANES}}$ were significantly different in Swiss men, due to the large number of subjects. Conversely, population means for $\text{FFM}_{\text{GENEVA}}$ and $\text{FFM}_{\text{NHANES}}$ (Table 2, Fig. 1) were not significantly different in Swiss men. Two-factor ANOVA also was not significant for FFM and FFM by age but was

significant for age in men and confirmed the non-significant difference between $\text{FFM}_{\text{GENEVA}}$ and $\text{FFM}_{\text{NHANES}}$ in men.

FFM in US men, who weighed 4.2 to 12.0 kg more than the Swiss men, was significantly higher (+2.1 to +6.0 kg) than FFM in Swiss men, except for non-significant differences in 20- to 29-y-old subjects by the Geneva equation (Table 2, Fig. 1).

Overall $\text{FFM}_{\text{NHANES}}$ was 1.5 kg higher than $\text{FFM}_{\text{GENEVA}}$ in Swiss women. The difference was lowest in the youngest subjects (1.2 kg) and highest in the oldest subjects (+3.2 kg; Table 2, Fig. 1, top). Thus, there appears to be an age-related effect of the BIA equations in women. Two-factor ANOVA was significant for FFM, age, and an interaction between FFM and age in women, thus confirming the significant differences between $\text{FFM}_{\text{GENEVA}}$ and $\text{FFM}_{\text{NHANES}}$ in women.

FFM in US women, who weighed 2.3 to 12.1 kg more than Swiss women, was significantly higher (+1.3 to +2.1 kg, respectively) than $\text{FFM}_{\text{GENEVA}}$ in Swiss women except for non-significant differences in subjects 20 to 29 y old (Table 2, Fig. 1). FFM in US women was significantly lower (−1.3 and −1.9 kg in women ages 20 to 29 y and 70 to 79 y, respectively) and non-significantly higher than $\text{FFM}_{\text{NHANES}}$ in Swiss women ages 30 to 69 y.

BF and %BF

The population means for $\text{BF}_{\text{GENEVA}}$ and $\text{BF}_{\text{NHANES}}$ (Table 3) were not significantly different in Swiss men, except in those ages 20 to 29 y. The Geneva equation produced a slightly lower BF value in the youngest group and a higher BF in the oldest men than did the NHANES equation. Two-factor ANOVA was not significant for BF and BF by age in men but was significant for age in men, thus confirming the non-significant difference between $\text{BF}_{\text{GENEVA}}$ and $\text{BF}_{\text{NHANES}}$ in men. The BF value in US men, who weighed 4.2 to 12.0 kg more than the Swiss men, was significantly higher (+1.5 to +6.4 kg) than that in the Swiss men by the Geneva and NHANES equations.

Mean values of $\text{\%BF}_{\text{GENEVA}}$ and $\text{\%BF}_{\text{NHANES}}$ (Table 3, Fig. 1) were also significantly higher in Swiss men ages 20 to 49 y and non-significantly higher in older subjects. Two-factor ANOVA was significant for %BF, age, and %BF by age in men. The %BF value was significantly higher in US men than in Swiss men (+1.3% to 4.6% versus $\text{FFM}_{\text{GENEVA}}$ and $\text{FFM}_{\text{NHANES}}$), and weight in US men was 11.2% higher than in Swiss men. Mean values of $\text{BF}_{\text{GENEVA}}$ and $\text{BF}_{\text{NHANES}}$ (Table 3) were significantly different in Swiss women. The Geneva equation produced higher BF values than did the NHANES equation (+1.2 to 3.2 kg). Two-factor ANOVA was significant for %BF, age, and %BF by age in women.

Values of BF in US women, who weighed 2.3 to 12.1 kg more than the Swiss women, was significantly higher (+4.8 to +11.8 kg, respectively, except for BF in those ages 70 to 79 y) than values of $\text{BF}_{\text{GENEVA}}$ or $\text{BF}_{\text{NHANES}}$ in Swiss women.

Table 2

FFM of healthy non-Hispanic white subjects in Switzerland, estimated by Geneva and NHANES equation and compared with US data

Age (y)	Men**			Women††		
	Swiss		US	Swiss		US
	FFM _{GENEVA}	FFM _{NHANES}	FFM _{NHANES}	FFM _{GENEVA}	FFM _{NHANES}	FFM _{NHANES}
20–29	60.4 ± 5.7	59.7 ± 7.0*†	61.3 ± 9.5§¶	43.2 ± 4.1	44.4 ± 4.8*‡	42.8 ± 5.9§¶
30–39	60.5 ± 5.8	59.9 ± 7.1*†	63.6 ± 10.5 ¶	43.2 ± 4.2	44.5 ± 5.1*‡	45.0 ± 6.9 ¶
40–49	60.0 ± 5.7	59.6 ± 7.0*†	64.6 ± 10.6 ¶	43.3 ± 4.2	44.6 ± 4.9*‡	44.8 ± 6.9 ¶
50–59	58.9 ± 5.4	58.6 ± 6.6*†	64.6 ± 8.8 ¶	43.3 ± 4.5	45.1 ± 5.3*‡	45.4 ± 6.7 ¶
60–69	57.2 ± 5.3	57.1 ± 6.6†	62.3 ± 8.9 ¶	42.0 ± 4.7	44.3 ± 5.5*‡	43.6 ± 6.3 ¶
70–79	56.3 ± 5.9	57.0 ± 6.9*†	59.1 ± 8.6 ¶	41.0 ± 4.9	44.2 ± 5.6*‡	42.3 ± 6.5 ¶

FFM, fat-free mass (kg); NHANES, National Health and Nutrition Examination Survey; US, American

* $P < 0.001$, FFM_{GENEVA} versus FFM_{NHANES}; paired t test.† Difference between population means (see MATERIALS AND METHODS): FFM_{GENEVA} versus FFM_{NHANES} non-significant.‡ Difference between population means (see MATERIALS AND METHODS): FFM_{GENEVA} versus FFM_{NHANES} significant.§ Difference between population means (see MATERIALS AND METHODS): FFM_{GENEVA} versus US non-significant.|| Difference between population means (see MATERIALS AND METHODS): FFM_{GENEVA} versus US significant.¶ Difference between population means (see MATERIALS AND METHODS): FFM_{NHANES} versus US non-significant.¶ Difference between population means (see MATERIALS AND METHODS): FFM_{NHANES} versus US significant.** Two-way analysis of variance: $P = 0.14$ for FFM_{GENEVA} versus FFM_{NHANES}, $P < 0.001$ for age, and $P = 0.58$ for age \times FFM.†† Two-way analysis of variance: $P = 0.001$ for FFM_{GENEVA} versus FFM_{NHANES}, $P < 0.001$ for age, and $P = 0.002$ for age \times FFM.

Mean values of %BF_{GENEVA} and %BF_{NHANES} (Table 3, Fig. 1) were significantly different in Swiss women. The Geneva equation produced higher %BF values (+1.9 to 4.9%) than did the NHANES equation. The %BF value was significantly higher in US women than in Swiss women (+4.3% to 10.7% versus %BF_{GENEVA} and %BF_{NHANES}, except for BF in those ages 70 to 79 y).

Discussion

The purpose of this study was to 1) determine the validity of body composition derived by two BIA equations (Geneva and NHANES III) in subjects living in Switzerland and 2) compare the body composition calculated by two equations (Geneva and NHANES III) of Swiss white with that of North American white adults. The findings showed good agreement between FFM_{GENEVA} and FFM_{NHANES} in men. However, FFM_{NHANES} was significantly higher than FFM_{GENEVA} in women. Values of BF and %BF were significantly higher in US subjects who also have greater weights than the Swiss adults.

Comparison of FFM by BIA with reference method

We performed an internal validation (Appendices A and B) of the previously validated Geneva equation [11] and the NHANES III equation [10] against DXA (Hologic QDR 4500) in Swiss subjects. The FFM_{GENEVA} was non-significantly different from the FFM_{DXA} (Appendix B, $n = 222$) in men. The FFM_{NHANES} differed significantly from FFM_{DXA} but was not considered clinically significant (+0.3 kg). Thus, the NHANES and Geneva equations appear to estimate body composition equally well in men.

The FFM_{GENEVA} was not significantly different from the FFM_{DXA} (Appendix B, $n = 164$) in women, whereas FFM_{NHANES} was significantly higher (+2.3 kg) than FFM_{DXA} (Appendix B). The FFM_{NHANES} was progressively higher than the FFM_{DXA} (+1.2 kg for those 20 to 29 y old and +3.1 kg for those 70 to 79 y old; data not shown), suggesting an age-dependent bias. The difference between FFM_{BIA} and FFM_{DXA} in women exceeded the between-method limits of agreement by approximately 2.0 kg [9].

The NHANES III equation was validated against a four-compartment model (deuterium dilution, DXA, and hydrostatic weighing). The Geneva equation was validated against a three-compartment model (DXA). We have no explanation for the sex differences in validity between these BIA equations. NHANES uses separate equations for men and women, whereas Geneva uses the same equation for men and women, but it includes a factor for sex differences. DXA is not considered a gold standard for FFM and BF [17,18]. DXA (QDR-4500) has been reported to overestimate FFM and underestimate BF by 3% to 5% in elderly subjects compared with criterion methods [19,20] and to produce errors in estimation of soft tissue composition associated with increased body thickness. Soft tissue fat content would be underestimated if anteroposterior diameters exceeded 25 mm [21]. Whether or not body thickness could account for these sex differences is not known. However, the Geneva equation (based on DXA_{QDR-4500}) produced FFM values similar to those of the NHANES equation in men and lower FFM values than the NHANES equation in women, suggesting that the FFM was not overestimated by DXA_{QDR-4500} in our subjects. The differences between the Geneva and NHANES III equations in women are not readily explainable. Although the NHANES III equation

Table 3
Body fat of healthy non-Hispanic white subjects, estimated by Geneva and NHANES equations and compared with US data

Age (y)	Men**			Women††			Men‡‡			Women§§		
	Swiss		US	Swiss		US	Swiss		US	Swiss		US
	BF _{GENEVA}	BF _{NHANES}	BF _{NHANES}	BF _{GENEVA}	BF _{NHANES}	BF _{NHANES}	%BF _{GENEVA}	%BF _{NHANES}	%BF _{NHANES}	%BF _{GENEVA}	%BF _{NHANES}	%BF _{NHANES}
20–29	13.0 ± 4.9	13.8 ± 4.6**	17.9 ± 8.7	15.7 ± 4.6	14.5 ± 4.0**	20.5 ± 9.6	17.3 ± 4.7	18.6 ± 4.8**	21.8 ± 6.2	26.3 ± 5.1	24.4 ± 4.6**	31.0 ± 7.5
30–39	14.6 ± 5.3	15.2 ± 4.8*†	20.4 ± 8.5	15.7 ± 5.2	14.5 ± 4.8**	24.1 ± 12.3	19.0 ± 4.9	20.0 ± 4.9**	23.6 ± 5.8	26.1 ± 5.5	24.2 ± 5.3**	33.0 ± 8.5
40–49	15.5 ± 5.5	15.9 ± 5.1*†	21.3 ± 8.5	16.4 ± 5.7	15.1 ± 5.2**	25.9 ± 10.9	20.1 ± 5.1	20.8 ± 5.1**	24.2 ± 5.7	26.9 ± 5.7	24.7 ± 5.5**	35.4 ± 6.9
50–59	15.9 ± 6.1	16.3 ± 5.7*†	22.3 ± 8.3	18.5 ± 5.8	16.8 ± 5.2**	28.6 ± 11.6	20.7 ± 5.6	21.4 ± 5.5*†	25.1 ± 6.0	29.3 ± 5.6	26.6 ± 5.3**	37.3 ± 7.1
60–69	17.2 ± 6.0	17.4 ± 5.3*†	22.7 ± 7.7	21.0 ± 7.1	18.8 ± 6.3**	26.7 ± 9.9	22.5 ± 5.4	23.0 ± 4.9*†	26.2 ± 5.5	32.6 ± 6.6	29.1 ± 6.0**	36.9 ± 6.9
70–79	18.8 ± 6.0	18.1 ± 5.4*†	20.3 ± 6.8	23.7 ± 7.2	20.5 ± 6.4**	24.8 ± 9.3 [§]	24.6 ± 5.1	23.8 ± 4.9*†	25.1 ± 5.5 [§]	35.9 ± 5.7	31.0 ± 5.4**	35.9 ± 6.9 [§]

BF, body fat (kg); %BF, percentage of body fat; NHANES, National Health and Nutrition Examination Survey; US, American

* $P < 0.001$, BF/%BF_{GENEVA} versus BF/%BF_{NHANES}, paired t test.

† Difference between population means (see MATERIALS AND METHODS): BF/%BF_{GENEVA} versus BF/%BF_{NHANES} non-significant.

‡ Difference between population means (see MATERIALS AND METHODS): BF/%BF_{GENEVA} versus BF/%BF_{NHANES} significant.

§ Difference between population means (see MATERIALS AND METHODS): BF/%BF_{GENEVA} versus BF/%BF US non-significant.

|| Difference between population means (see MATERIALS AND METHODS): BF/%BF_{GENEVA} versus BF/%BF US significant.

Difference between population means (see MATERIALS AND METHODS): BF/%BF_{NHANES} versus BF/%BF US non-significant.

¶ Difference between population means (see MATERIALS AND METHODS): BF/%BF_{NHANES} versus BF/%BF US significant.

** Two-way analysis of variance: $P = 0.07$ for BF, $P < 0.001$ for age, and $P = 0.35$ for age \times BF.

†† Two-way analysis of variance: $P = 0.001$ for BF, $P < 0.001$ for age, and $P = 0.010$ for age \times BF.

‡‡ Two-way analysis of variance: $P = 0.001$ for %BF, $P < 0.001$ for age, and $P = 0.040$ for age \times %BF.

§§ Two-way analysis of variance: $P = 0.001$ for %BF, $P < 0.001$ for age, and $P = 0.001$ for age \times %BF.

was validated against a “gold standard” four-compartment model, which accounts for tissue hydration, body density, and bone mineral content and therefore is considered more accurate than DXA, our data suggest that the NHANES equation might have overestimated FFM in women. It is surprising that Swiss women who had lower values for weight and BMI would have similar FFM values as US women who had higher values of weights and BMI. Further research is necessary to determine the discrepancies in FFM between the two BIA equations in women.

BMI in European and US adults

Mean values for weight (Table 1, Fig. 1, top) and BMI were significantly higher in US than in Swiss men and women and were not due to differences in height. NHANES data (collected from 1988 to 1994) do not reflect recently reported weight gains in the US population. Swiss adults were measured between 1990 and 2002.

Median BMI and prevalence of overweight and obesity have been reported to be lowest in French and Swiss subjects (25.3 kg/m² in men and 23.0 kg/m² in women), followed by Dutch and Irish subjects [22] and German and Swedish subjects [23] and highest in Southern Italian and Spanish subjects (27.4 kg/m² in men and 28.5 kg/m² in women) [23]. The Southern Italian and Spanish BMI values were similar to the US BMI values (Table 1). Thus, the Swiss subjects were at the lower end of the overweight/obese spectrum of European countries and had significantly lower BMI values than did North American non-Hispanic white adults.

FFM and BF in Swiss and US adults

In Swiss men, mean weight was greater in middle-age than in young subjects and remained stable thereafter, whereas FFM was lower in Swiss men older and younger than 50 y (Table 2, Fig. 1) and BF and %BF values (Table 3, Fig. 1) increased throughout adulthood. Weight and FFM (Fig. 1) increased (+ 7.9 and +3.3 kg) in US men until age 60 y, and BF increased until age 70 y. The greater weight in US men resulted in higher values of FFM, BF, and %BF (Fig. 1) in US than in Swiss men. The earlier change (decrease) in FFM in Swiss men versus US men suggests that the age-related weight increase was not sufficient to offset an age-related FFM decrease and thus resulted in a lower ratio of FFM to weight in older than in younger Swiss men. Longitudinal studies are necessary to confirm these observations.

In Swiss women, mean values for weight (Table 1), BF, and %BF (Table 3, Fig. 1 bottom) were relatively stable until age 49 y and increased thereafter, whereas FFM was stable until age 59 y and decreased thereafter. In US women, values for weight, FFM, BF, and %BF (Table 3, Fig. 1 bottom) were highest in those 50 to 59 y old. The greater weights in US women resulted in higher values of

FFM, BF, and %BF (Tables II and III, Fig. 1) in US than in Swiss women by FFM_{GENEVA}. FFM_{NHANES} in Swiss women remained stable throughout adulthood. The data showed no differences in FFM_{NHANES} between US and Swiss women, despite greater weights in US women. This finding leads us to suspect that the NHANES equation might have overestimated FFM in Swiss women.

As noted by the NHANES study, mean reference values are not an indication of an ideal or desirable level of FFM, BF, or %BF. Mean BMI value exceeded the recommended threshold for healthy weight (BMI > 25.0 kg/m²) in Swiss men older than 60 y and in women older than 70 y; in US subjects, mean BMI values exceeded the recommended threshold in subjects 30 y and older. BMI values from 25 to 27 kg/m² do not necessarily indicate increased risk in elderly subjects [6,24].

Based on previously determined “overweight” %BF ranges (21.8% to 28.7% in men and 33.2% to 39.9% in women), we found that 33.4% of Swiss men and 15.8% of Swiss women were overweight and that 4.5% and 3.7% were obese, respectively, compared with 30.0% and 15.4% who were overweight (BMI = 25.0 to 29.9 kg/m²) and 3.3% and 2.5% who were obese (BMI > 30.0 kg/m²). This information is not available for the US data, but the prevalence of overweight and obesity would be expected to be higher than in Swiss subjects. The variations in prevalence of overweight and obesity by BMI and %BF were small in healthy subjects but were found to be larger in patients at hospital admission (Kyle et al., unpublished data).

Low FFM is a major contributor to the loss of functional ability and health [25]. Two percent of men and 10.6% of women in this study had a low FFM index (<16.7 kg/m² in men and <14.6 kg/m² in women) [26], corresponding to a BMI lower than 18.5 kg/m².

Study limitations

The data in this study are cross-sectional. Differences in FFM or BF between age groups cannot be interpreted as a decrease in FFM or an increase in BF with age. Longitudinal studies are required to determine representative changes in FFM and BF with age.

Although subjects were not randomly selected, they were representative of the Swiss population in terms of median BMI. The median BMI values were 23.7 kg/m² for men and 21.9 kg/m² for women in this study compared with median BMI values of 25.3 and 23.0 kg/m², respectively, in a randomly selected Genevan population ages 40 to 59 y [22]. The BMI would be expected to be lower in this study because 49% of men and women were younger than 40 y.

Differences less than 2% to 3% (1 to 2 kg of FFM or <1%BF) would be within the limits of error of the method and would not be considered clinically significant, despite *t* tests being significant, because of the large number of subjects. Body composition estimates in this study were not based on criterion measures but were calculated from BIA

resistance and reactance and anthropometric measurements. DXA is not considered a gold standard method for FFM and BF [17,18].

Conclusion

The NHANES and Geneva BIA equations estimate body composition equally well in men. Further research is necessary to determine the discrepancies in FFM between BIA equations in women. The greater weight of the US subjects yielded higher values for FFM, BF, and %BF in US than in Swiss men and women. Free internet-based access of data from the large published studies could aid in promoting the use of reference data by investigators and clinicians using BIA.

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Appendix A

Anthropometric and bioelectrical impedance analytic characteristics of healthy white subjects living in Switzerland

	Men	Women
<i>n</i>	222	164
Age (y)	48.6 ± 17.4	52.9 ± 19.1
Height (cm)	176.0 ± 7.2	163.1 ± 6.1
Weight (kg)	78.4 ± 9.8	64.0 ± 10.2
Body mass index (kg/m ²)	25.3 ± 2.9	24.1 ± 3.6
Resistance (Ω)	457 ± 47	560 ± 58
Reactance (Ω)	56.1 ± 8.9	62.2 ± 10.3

Appendix B

Comparison of FFM by DXA and BIA as estimated by Geneva and NHANES equations*

	FFM _{DXA}	FFM _{GENEVA}	Δ DXA- GENEVA	r^2 [†]	Pure error [‡]	FFM _{NHANES}	Δ DXA- NHANES	r^2 [†]	Pure error [‡]
Men	61.1 ± 6.3	61.1 ± 6.1	0.0 ± 1.8	0.92	1.8	61.5 ± 7.3 [§]	−0.3 ± 2.5	0.89	2.5
Women	43.6 ± 5.0	43.7 ± 4.7	0.1 ± 1.5	0.91	1.5	45.9 ± 5.6 [§]	−2.3 ± 2.0	0.87	2.6

BIA, bioelectrical impedance analysis; DXA, dual-energy x-ray absorptiometry; FFM, fat-free mass (kg); NHANES, National Health and Nutrition Examination Survey

* Values are mean ± standard deviation.

[†] Correlation between BIA and DXA.

[‡] Pure error = $(\sum[\text{FFM}_{\text{DXA}} - \text{FFM}_{\text{BIA}}])^{1/2}/n$.

[§] $P < 0.05$, FFM_{DXA} versus FFM_{GENEVA} or FFM_{NHANES}, paired t test.

^{||} $P < 0.05$, FFM_{GENEVA} versus FFM_{NHANES}, paired t test.